LA-UR-82-1667

CONF-820819--5

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LA-UR--82-1667

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MASTER

TITLE: An Economic Analysis of the Integrated Heating and Cooling Potential of a Residential Passive-Solar Water Wall Design

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SUBMITTED TO: For presentation at the American Section of the International Solar Energy Society, Inc., PASSIVE 82 in Knoxville, TN, August 29 to September 3, 1982.

Los Alamos

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AN ECONOMIC ANALYSIS OF THE INTEGRATED HEATING AND COOLING POTENTIAL OF A RESIDENTIAL PASSIVE SOLAR WATER WALL DESIGN

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ABSTRACT

The heating potential of residential water wall designs has been analyzed for many years. Because this past work has been confined strictly to heating potential, it has understated the true energy savings potential of water walls. Preliminary performance estimates for the heating and cooling potential of water walls have recently been made available by the Solar Energy Group (Q-11) at Los Alamos National Laboratory (1). These estimates include the Btu displacement that is attributable to a 300-square foot water wall design in a 1200-square foot residence. The design is for a forced ventilation water wall system that includes the fans and ducting necessary to achieve a 3000-cfm flow of air.

The cooling and heating energy displacement estimates are combined with appropriate region-specific fuel prices, system costs, and general economic parameters in a life-cycle cost analysis of this fixed-size water wall design. The economic indicators used to discuss the results include net present value and a total cost goal. Input data and results are presented in mapped form and used to assess the energy savings potential of the water wall in 220 regions of the continental United States.

1. INTRODUCTION

The passive residential design under consideration here is a 300-square foot water wall. The wall is nine inches thick and has a total heat capacity of 14,000 Btu/^{o}F. It is assumed that the south side of the house has a good selective surface. Outside air is brought in at 3000-cfm when its temperature is below the storage temperature of the water wall. The air cools the storage at 80% effectiveness. The cooling performance estimates assume that the entire cooling load can be absorbed by the storage but that refrigerative cooling takes over when the storage reaches a temperature of 78^{o}F. The heating performance estimates assume that the south wall has no net heat gain or loss.

It is important to note here that the fans and ducting are used in the cooling mode only, resulting in a forced ventilation water wall system for cooling and a natural ventilation water wall for heating. No heating performance measures for a forced ventilation design were available to the authors at the time of this analysis. Physical performance for heating should be higher for a forced ventilation design than for the natural ventilation system. Therefore, the measures of economic performance and attractiveness discussed below should be considered conservative.

The residence modeled here represents a 1200-square foot tract home with a 50-foot east-west dimension and a 24-foot north-south dimension. The window area is 15% of the wall area and evenly distributed. All windows are double glazed. Infiltration is one-half air change per hour. The walls and roof have R20 insulation. This results in a fairly 'tight' house with a heating load of 7200-Btu/^{o}F-day. Two fuel use regimes are analyzed--all electric heating and cooling system and a gas heating system combined with electric refrigerative cooling.

We have previously addressed the economic performance of this passive design for cooling alone (2). We concluded at that time that the design shows the most economic promise in regions with high cooling loads, fairly low relative humidity and high electricity prices. The economic performance for cooling and heating should be better than for cooling alone. The regions with good performance for cooling and a significant heating load coupled with high heating fuel prices would obviously be the regions with the best integrated economic performance.

The economic calculations are based on life-cycle costing. All-one time and recurring costs and benefits are considered. The cost component includes annual payments for the design back-up fuel cost, and other annual costs including property taxes and operating and maintenance expenses. The benefits component includes the value of the energy displaced by the design along with such things as property tax and mortgage interest deductions. The primary determinants of the economic performance are conventional fuel costs and design performance.

The economic methodology is explained in detail in the next section. Maps portraying the geographic distribution of major input variables are included.

The results of the economic analysis are detailed in the final section of the paper. Maps are presented to show the net present value and cost goals (maximum allowable costs) associated with the two fuel use regimes for 220 regions in the continental US. Conclusions are offered concerning the economic outlook for this particular passive design.

2. METHODOLOGY

One of the most important inputs to the economic calculations is the heating and cooling performance of the passive design. This performance has two components--millions of Btu's (mmBtu) load and mmBtu load displacement for both heating and cooling. These inputs are shown on Maps 1 to 4. Map 1 portrays the heating load in mmBtu. Heating loads are greatest in the Great Lakes region and northern Mid-America and smallest in Florida and the Gulf Coast regions. The heating load displaced by the water wall design (natural ventilation only) is shown in Map 2. The solar savings are greatest in the southern portion of the Rocky Mountains. Since this is an area of high heating load, it can be concluded that the physical performance of the water wall, as measured by a solar savings fraction, is best in the southern Rocky Mountain region.

Map 3 portrays the mmBtu cooling load by region. The cooling loads are greatest in the Gulf Cost regions. Cooling load displacement, Map 4, is greatest in the entire southern tier of regions. When these two measures are combined, it can be concluded that the physical performance is best in the southwestern regions of the US. The water wall (forced ventilation design) replaces a larger proportion of the cooling load in these drier regions.

Cooling and heating loads are combined with region-specific fuel prices to yield an annual fuel bill estimate for each region. This is done for both a gas heating/-electric cooling and all-electric fuel use regime (Maps 5 and 7, respectively). Dollar value of the combined heating/-cooling performance of the water wall design is then used to calculate a percent reduction in annual fuel bill. These calculations are graphically portrayed in Maps 6 and 8, respectively. The regions showing the greatest percent reduction in fuel bill are those in which a large proportion of the load is displaced by the water wall and fuel prices are relatively high.

The economic indicators calculated for this analysis are net present value and total cost goal. The net present value is defined as the present value of the stream of benefits associated with the water wall design. Costs and benefits are compared on an annual basis for 30 years. Costs include down payment (in the first year), the annual mortgage payment, property taxes due to the solar component, operating and maintenance expenses, and the cost of conventional fuel to satisfy the non-solar portion of heating and cooling loads. Benefits include mortgage interest deduction; property tax deduction, applicable tax credits, the value of the conventional fuel displaced by the water wall, and resale value realized in the 30th year. Cost are subtracted from benefits each year. The resulting net cash flow is summed for all years and discounted to yield the net present value of the design.

The total cost goal represents the maximum (allowable) first cost one could pay. This is equivalent to a net present value of zero. If this were the case, a consumer would be equally well off with either a water wall (with backup) or a conventionally heated and cooled home. When the cost goal is very high compared to the available cost estimate, the design would be a very good investment. The cost goal is calculated by summing the annualized dollar value of heating and cooling fuel displaced. This figure, the annualized fuel bill displaced, is divided by a fixed charge rate to yield the total cost goal. It represents the present value of the fuel costs displaced by the design. The economic calculations have been briefly explained above. More detail can be found in Refs. 3 and 4. The results of these calculations (portrayed in Maps 9 to 12), along with conclusions as to their importance, are presented in the next section. The values of economic parameters used in the analysis are included in Table 1 below.

TABLE I

Economic Parameters

Period of Analysis	30 years
Down Payment	20%
Property Tax Rate	2%
Federal, State, and Local Tax Bracket	35%
Operating and Maintenance Rate	
(system cost)	1%
Annual Inflation Rate	8%
Real Interest Rate	8%
Real Discount Rate	5%
Resale Rate	100%
Annual Fuel Price Escalation Rate	
Electricity	2%
Natural Gas	5%
Estimated Design Cost	
(national average)	$5800

3. RESULTS AND CONCLUSIONS

By comparing the results of the annual fuel bill calculations and reduction of annual fuel bill, the regions with the greatest potential savings can be determined. The total annual fuel bills are greatest in the northeastern portion of the US and in western Nevada under both fuel regimes. The fuel bill reduction is greatest in portions of the northeastern US, the Gulf Coast, and northern Mid-America. The overlap of high fuel bills and greatest percent reduction of fuel bills occurs in portions of the northeastern US.

Residential fuel prices are the primary determinant of the outcome of the economic analysis. Areas with high fuel prices are characterized by good economic performance.

Net present values and cost goals for a natural gas-heating and electricity-cooling fuel regime are highest in the West where natural gas prices are consistently high. For the all electric fuel regime, however, the regions of high net present value and cost goals are scattered throughout the US, reflecting the lack of a strong geographic pattern for residential electricity prices.

The cost goal results compare favorably with available cost estimates for this water wall design, and we have found the design to be economically viable in about a fourth of the regions analyzed. Our cost goal estimates are conservative, however, for the following reasons. The fuel bills were based on 1981 fuel prices, which have since increased. Additionally, the heating performance estimates were based on a natural ventilation design. Heating performance of a forced ventilation design would be better and therefore increase the cost goals.

Extension of this work might include regional information concerning characteristic fuel regime and fuel use patterns in the economic analysis. Other significant fuel use regimes should also be considered. These additional elements would help target the most promising areas of the country for introduction of the water wall design.

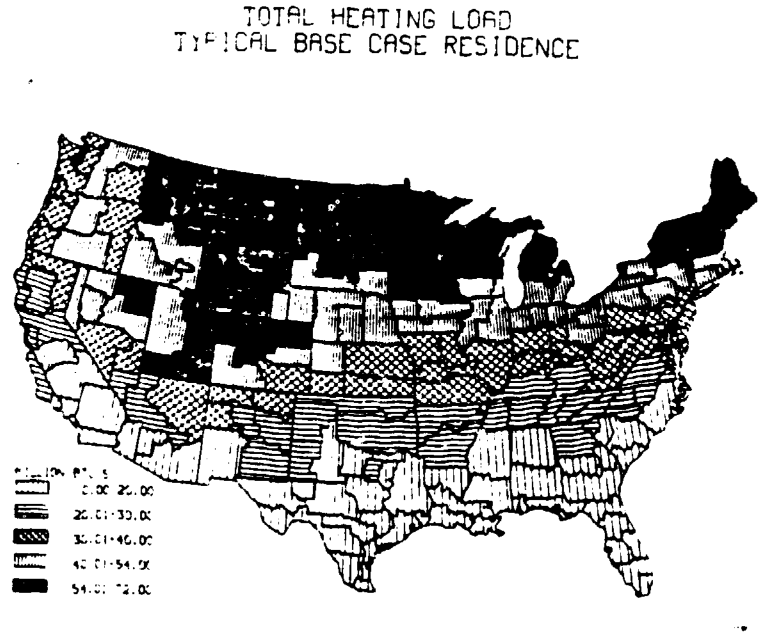
4. REFERENCES

(1) Q-11/3122A Memo to Dave Pellish, DOE, from Donald A. Neeper, Group Leader, Solar Energy Group, Los Alamos National Laboratory, June 9, 1981.

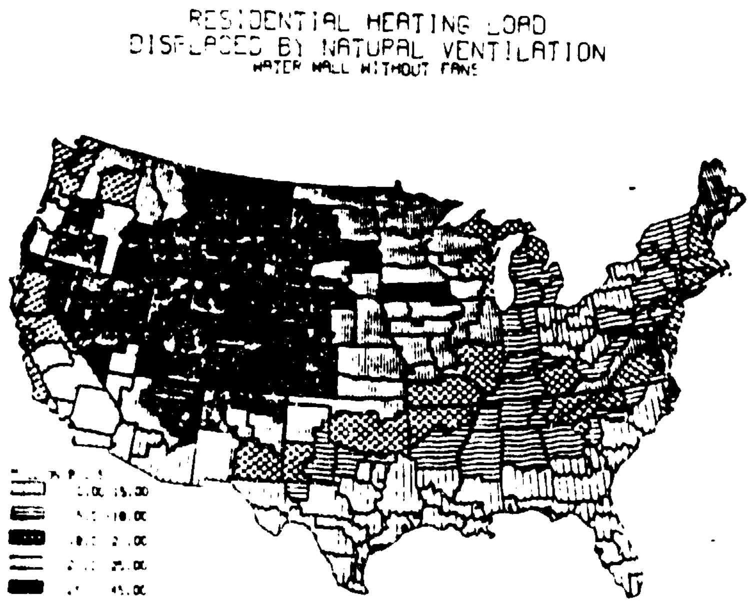
(2) Christina Kirschner, Carolyn Mangeng, Marilyn Yeamans, and Fred Roach, "Preliminary Economic Assessment of Residential Passive Solar Cooling Potential in the United States," Proceedings, American Section of the International Solar Energy Society Conference, Houston, Texas, June 1-5, 1982 (LA-UR-82-870).

(3) Audrey M. Perino, "A Methodology for Determining the Economic Feasibility of Residential or Commercial Solar Energy Systems," Sandia Laboratories report SAND78-0931, January 1979.

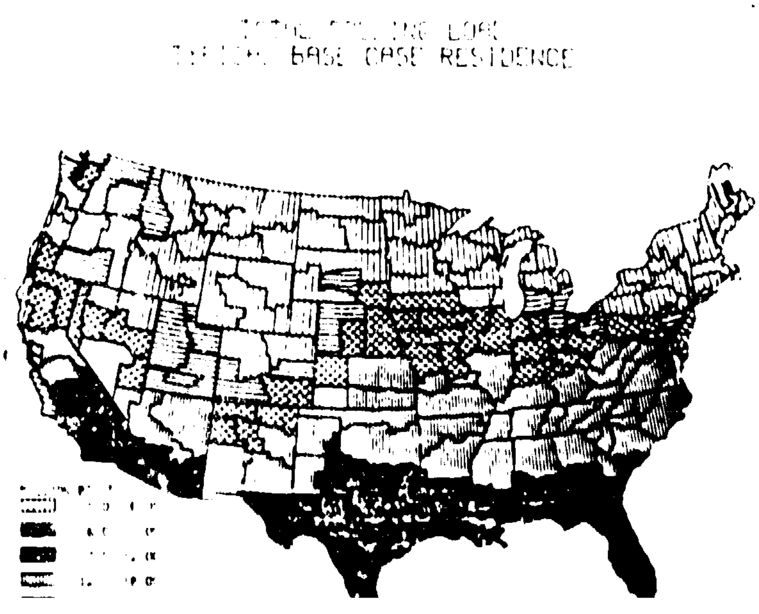
(4) Christina Kirschner, "The Role of Economic Analysis in Evaluating Passive Solar Designs," unpublished master's thesis, University of New Mexico, 1980.

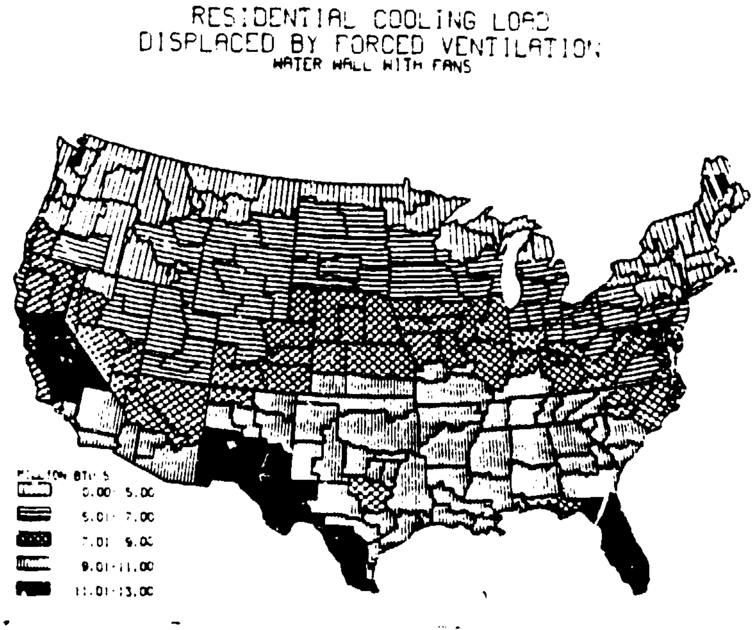


Map 1.



Map 2.





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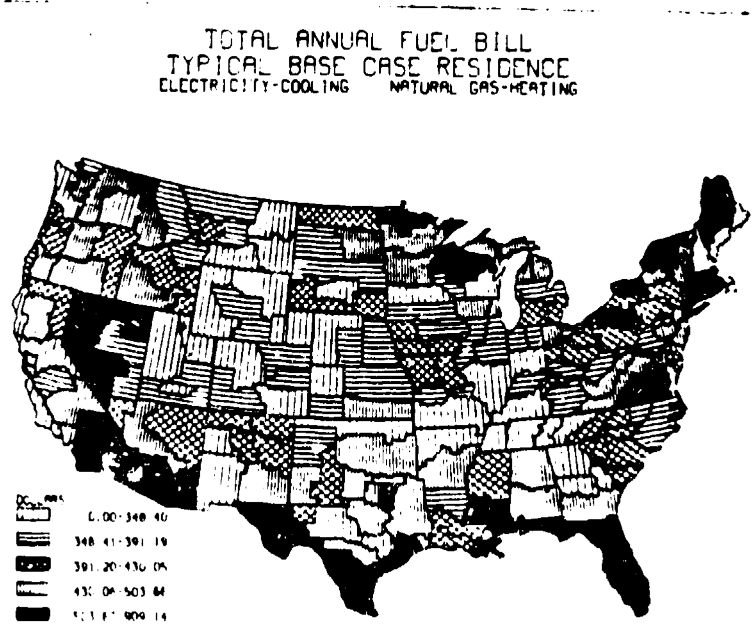

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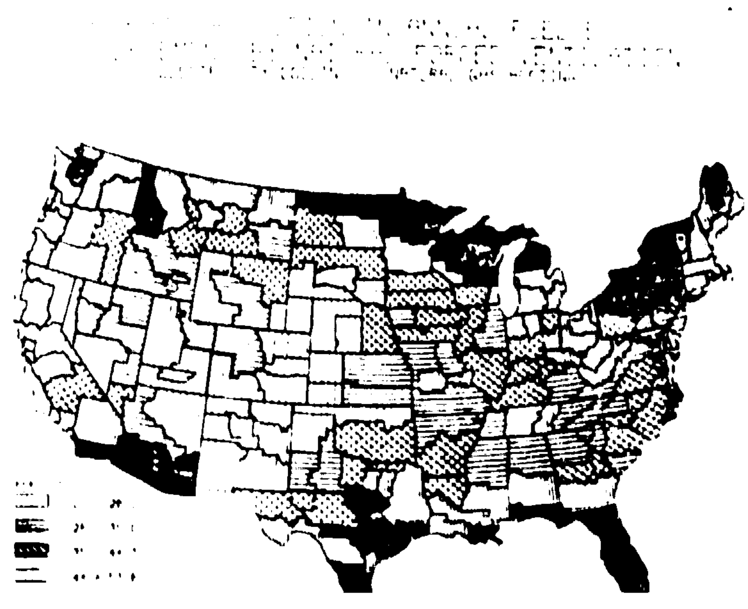
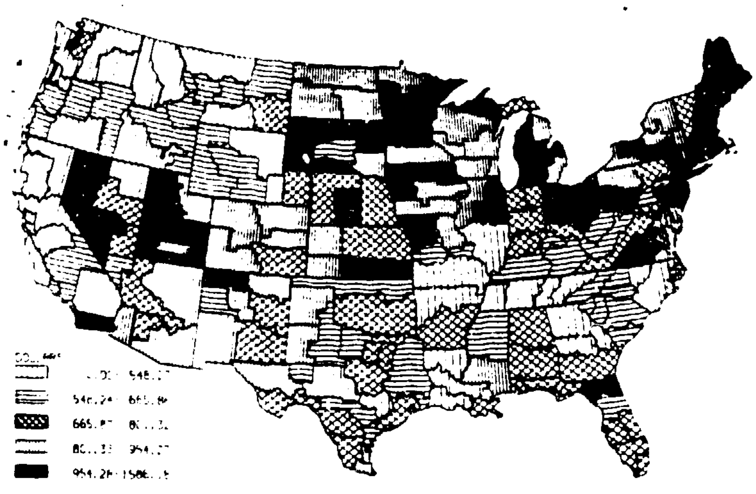
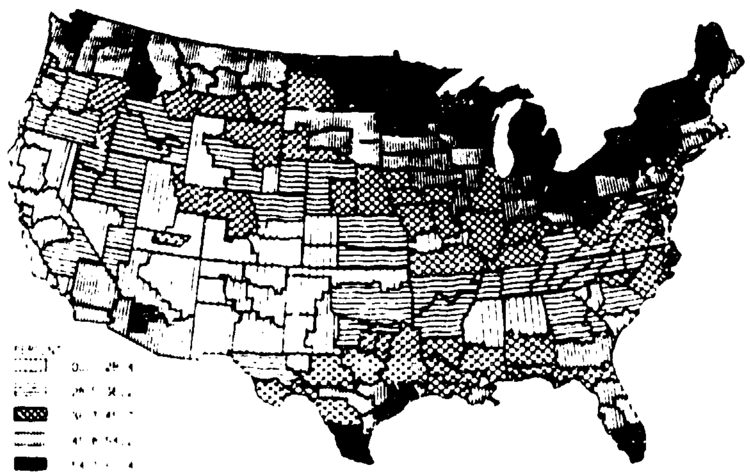


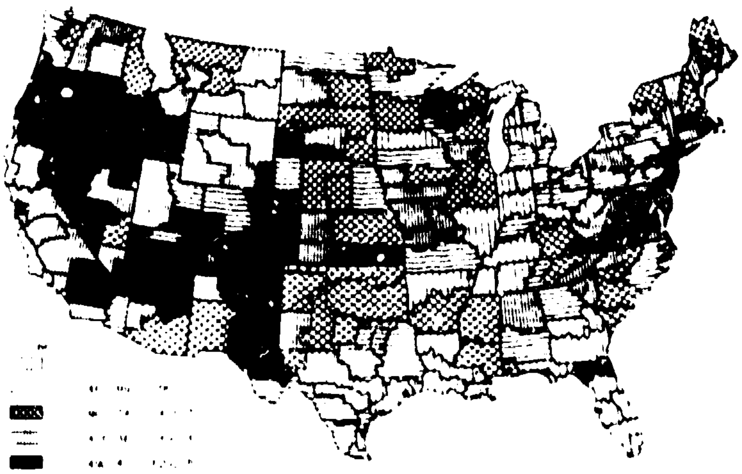


Map 7.

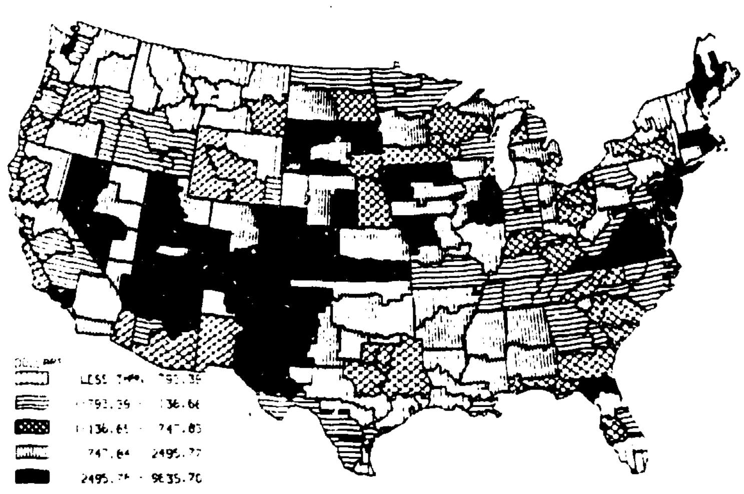
PERCENT REDUCTION IN ANNUAL FUEL BILL
DISPLACEMENT BY NATURAL/FORCED VENTILATION
ELECTRICITY-COOLING ELECTRICITY-HEATING



Map 8.

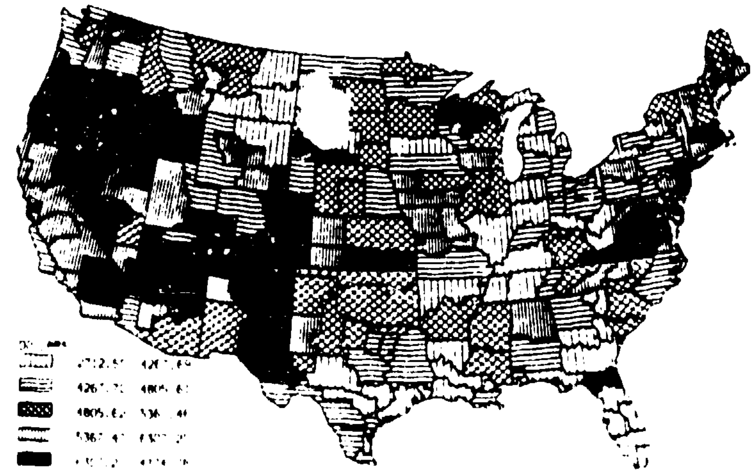


Map 9.

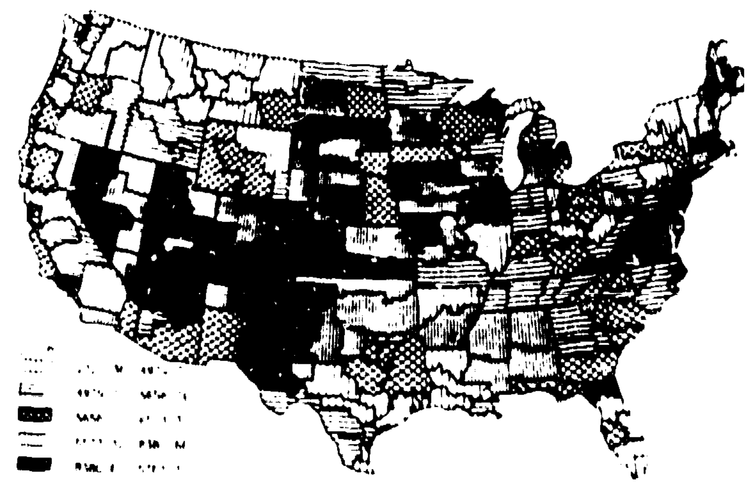


Map 10.

MAXIMUM ALLOWABLE SOLAR COSTS
DISPLACEMENT BY NATURAL/FORCED VENTILATION
ELECTRICITY-COOLING NATURAL GAS-HEATING



Map 11.



Map 12.